REPORT ON

RATIONALE FOR UTILIZING SOLIDIFICATION IN A HAZARDOUS WASTE TREATMENT FACILITY

PREPARED FOR

ONTARIO WASTE MANAGEMENT CORPORATION

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NOTES ON REPORT ARRANGEMENT

Sections are numbered with Arabic numerals, with hyphenated Arabic numerals used for page numbering within sections (1-1, 1-2, 1-3...).

Tables are numbered with Arabic numerals which designate the section and with Arabic numerals following a decimal point which designate the sequence within the section (Table 1.1, Table 1.2, Table 1.3...). Tables are assembled at the end of the text of each section.

Figures are numbered using the same system as used for Tables. Figures are assembled behind the Tables.

References are numbered with an "R" preceding an Arabic numeral designating the section and a decimal point followed by Arabic numerals identifying the references [(R1.1), (R1.2), (R1.3)]. References are noted throughout the text and are listed following the figures in each section.

Appendices are designated by alphabetical order and assembled together at the end of the report and numbered with the appendix character followed by a hyphenated Arabic numeral (A-1, A-2, A-3...), UNLESS NOTED OTHERWISE.

GENERAL

The term, solidification, has been used in this report to mean both "solidification" and "fixation" processes, which is in conformance with the terminology adopted by OWMC.

SECTION 1

INTRODUCTION

SECTION 1
INTRODUCTION

BACKGROUND

The Ontario Waste Management Corporation (OWMC) is a provincial Crown agency formally created in July 1981 by the Ontario legislature. OWMC's primary responsibility is to establish and operate a hazardous waste management facility in Ontario. As part of its work program, OWMC has identified technologies and developed a facility design for the treatment and disposal of hazardous wastes. The proposed treatment facility will consist of the following:

- o incineration plant,
- o physical/chemical treatment plant
- o solidification plant
- o engineered landfill

The incineration of organic wastes and the physical/chemical treatment of inorganic wastes will result in solid and concentrated liquid residues and final treated liquid effluent. The solid residues, concentrated inorganic liquid residues, and final treated liquid effluent will be processed further in the solidification plant before disposal in the engineered landfill. The solidification plant will be located in the same building as the physical/chemical treatment plant.

Solidification is a process where residues from the waste treatment processes are mixed with chemical reagents such as cement and sodium silicate and other additives to form a stable, solid material. The objective of the process is to produce a material which is both physically and chemically stable in the engineered landfill.

"Physically stable" means that the solids produced will not revert to their original liquid or sludge state if exposed to water in the ground. "Chemically stable"

means that the waste residues will be treated so that the rate at which these contaminants will dissolve in water (leaching) will be inhibited.

The background and rationale for including solidification in the design of OWMC's Facility has been presented in two earlier reports (R1.1, R1.2). The choice of rotary kiln incineration, physical/chemical treatment, solidification and an engineered landfill as the four major components of the Facility were subsequently confirmed in the report entitled "Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario" - July 1985 (R1.3).

SCOPE

The planning and development of the OWMC facility are based on three stated goals, in order of priority:

1. minimize the risk to human health;
2. minimize the impact to the environment;
3. minimize the cost to OWMC and the people of Ontario.

The above goals are, in effect, the driving force for facility site selection, system and technology evaluation, and process design in all areas of the proposed facility.

The balancing of health risks and environmental impacts against cost considerations is a continuing struggle for a project of this magnitude. The applicability of using solidification at a hazardous waste treatment facility has been questioned, citing cost effectiveness concerns.

OWMC has retained Engineering-Science (ES) to assess the rationale for the use of solidification as a final treatment step for all liquid and nonliquid waste residues generated by the physical/chemical processes and incineration plant at the proposed facility. The assessment, as presented in this report, has been carried out with the perspectives of industry experience and regulatory practices in the U.S. Three ultimate disposal methods have been included in this review: namely, engineered landfills, above-ground warehouses, and geological isolation. The emphasis has, however, been placed on landfill disposal of the wastes, as presently envisioned for the OWMC facility.

ASSESSMENT APPROACH

The question of using solidification as a final treatment step for the OWMC facility is an issue which has technical and economic as well as political overtones. Some of the issues are quantifiable while many others are qualitatively subjective, such as human health risk and environmental impact. The current regulatory situation in the United States appears to be analogous to the Ontario situation and much can be learned from exploring the U.S. hazardous waste land disposal regulations and their impact on solidification.

To prepare this assessment, Engineering-Science (ES) addressed the following topical areas in this report:

- o U.S. Regulatory Requirements Encouraging Solidification,
- o Developmental History of Hazardous Waste Solidification,
- o Applicability of Solidification to the OWMC Facility.

REPORT ORGANIZATION

Section 2 of this report explores U.S. regulatory requirements of the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments of 1984 (HSWA) which in total have placed increasingly stringent restrictions on the land disposal of hazardous wastes and encouraged the use of solidification. Section 3, Developmental History of Solidification, presents a brief overview of solidification and its proven success at reducing free liquids and leachability and also improving the physical-engineering properties of wastes, which impact subsidence and provide operational benefits during winter and prolonged wet periods. Section 4, Applicability of Solidification to OWMC, focuses on the U.S. regulatory experience combined with technical applicability of hazardous waste solidification to the OWMC facility. Lastly, conclusions and recommendations are presented in Section 5.

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R1.1 Generic Process Technologies Studies, The Proctor & Redfern Group, August 1982. 224 pp., Appendices.

R1.2 Ontario Waste Management Corporation, Facilities Development Process, Phase 3 Report, The Selection of Candidate Sites, OWMC, March 1984. 95 pp.

R1.3 A.D. Little of Canada Limited, Rationale for the Selection of Technologies and Systems for Treatment and Disposal of Special Wastes in Ontario - October 1986.

SECTION 2

RCRA REGULATIONS IMPACTING SOLIDIFICATION

SECTION 2
RCRA REGULATIONS IMPACTING SOLIDIFICATION

In 1976, the United States Congress passed the Resource Conservation and Recovery Act (RCRA), Public Law 94-580, which regulated non-hazardous and hazardous waste disposal. Subsequently, the United States Environmental Protection Agency (EPA) has promulgated regulations for the identification, treatment, and land disposal of hazardous wastes. In 1984, Congress passed the Hazardous and Solid Waste Amendments of 1984 (HSWA) which placed further restrictions on the land disposal of hazardous wastes. Much can be learned from a review of the technical information developed by EPA as well as a historical review of the regulations.

Figure 2.1 shows schematically the interrelationship between existing and proposed regulations in the U.S. impacting the applicability of solidification to land disposal of hazardous wastes. The following section discusses the information presented in Figure 2.1.

FREE LIQUID PROHIBITION

Free liquids in hazardous wastes placed in a long term containment system can potentially lead to leaking and migration of hazardous constituents (R2.1, R2.2, R2.3). The minimization of liquids in wastes destined for land disposal represents a major component of regulatory control in the U.S. Because of the prevailing use of landfills as the final disposal method, the U.S. regulations have been directed at minimization of liquids in landfills. EPA has taken steps in 1986 to prohibit the land disposal of free liquids (R2.4). The regulations address the following areas:

- Placement of bulk liquid hazardous waste or hazardous waste containing free liquids that readily separate from the solid portion of a waste under ambient temperature and pressure.
- The Paint Filter Test has been developed to determine the presence or absence of free liquids in the wastes (R2.5).
- If a hazardous waste fails the Paint Filter Test, it must be treated before being disposed of in a landfill. The treatment must not involve the use of a material which functions solely as an absorbent, and which will allow the treated waste to release liquids after being placed in the landfill.

- o The use of absorbents which can biodegrade is also prohibited as the hazardous constituents can eventually be released in the landfill. A limit of 1% of total organic carbon content is proposed as the criterion to determine whether a material is biodegradable.
- o Chemical stabilization is considered as an appropriate treatment technique for wastes which fail the Paint Filter Test. An unconfined compressive strength of 345kPa (50 psi) has been proposed as an indirect indication that adequate chemical stabilization has taken place.

LANDFILL BANNED WASTE

On May 28, 1986, EPA established a schedule setting forth the order in which listed hazardous wastes will be prohibited from land disposal, unless EPA can set appropriate standards or grant case-by-case exemptions. Pursuant to RCRA and HSWA, if EPA fails to set treatment standards or grant exemptions in accordance with this schedule, hazardous wastes will be subject to partial land disposal restriction or banned from land disposal. The schedule is as follows:

Waste Group	Date Restricted
Solvents and Dioxins	November 8, 1986
"California List"	July 8, 1987
First Third of Listed Wastes	August 8, 1988
Second Third of Listed Wastes	June 8, 1989
Final Third of Listed Wastes	May 8, 1990

Rather than specify mandatory treatment methods, EPA has set treatment standards which generators must meet prior to land disposal. These treatment standards are expressed as concentrations of a constituent, e.g., arsenic, as determined by the Toxicity Characteristic Leaching Procedure (TCLP)(R2.6). Although specific treatment is not mandated, it is meant to reflect Best Demonstrated Available Technology (BDAT). For inorganic wastes, solidification is typically used by EPA to reflect BDAT. This regulatory process is shown in Figure 2.1. The implementation of the land ban coupled with the new TCLP is resulting in inorganic listed wastes and other residues such as incinerator ash having to be solidified before land disposal.

LIQUID RELEASE TEST

EPA is proposing the use of the Liquid Release Test as the procedure for determining whether the treated waste is "structurally stable", i.e., that it will not release liquids when compressed under the pressure inside the landfill (R2.7). This test might eventually replace the Paint Filter Test, which does not account for the effects of the overburden pressure (see Figure 2.1). This test is based on the concept of a confined compression test which involves subjecting the treated waste in a confined (rigid wall) apparatus, to a compressive force and examining the liquid release characteristics.

WASTE BEARING STRENGTH

Wastes which have a high oil or clay content or whose properties are hygroscopic such as calcium chloride can pass the Paint Filter Test but may have inadequate bearing strength (see Figure 2.1). This could pose a problem depending upon the volume of waste to be disposed and the lift height in the secure landfill. Lift height and bearing strength are not specified on current RCRA land disposal permits (R2.8). It is possible in the future when a data base is established regarding subsidence at secure landfills that a minimum bearing strength value may be recommended and a testing procedure specified. As of this date, EPA is not proposing a bearing strength evaluation.

SUMMARY

The Resource Conservation and Recovery Act (RCRA) and the more recent Hazardous and Solid Waste Amendments (HSWA) have provided incentives and controls for designing and operating hazardous waste land disposal facilities. The regulations ban the disposal of free liquids into landfills and are also banning selected wastes from land disposal if not adequately treated.

Solidification is being recommended as a technology available for treating selected banned waste prior to landfilling. It is also being recommended for treating residues from other treatment technologies including chemical treatment and incineration.

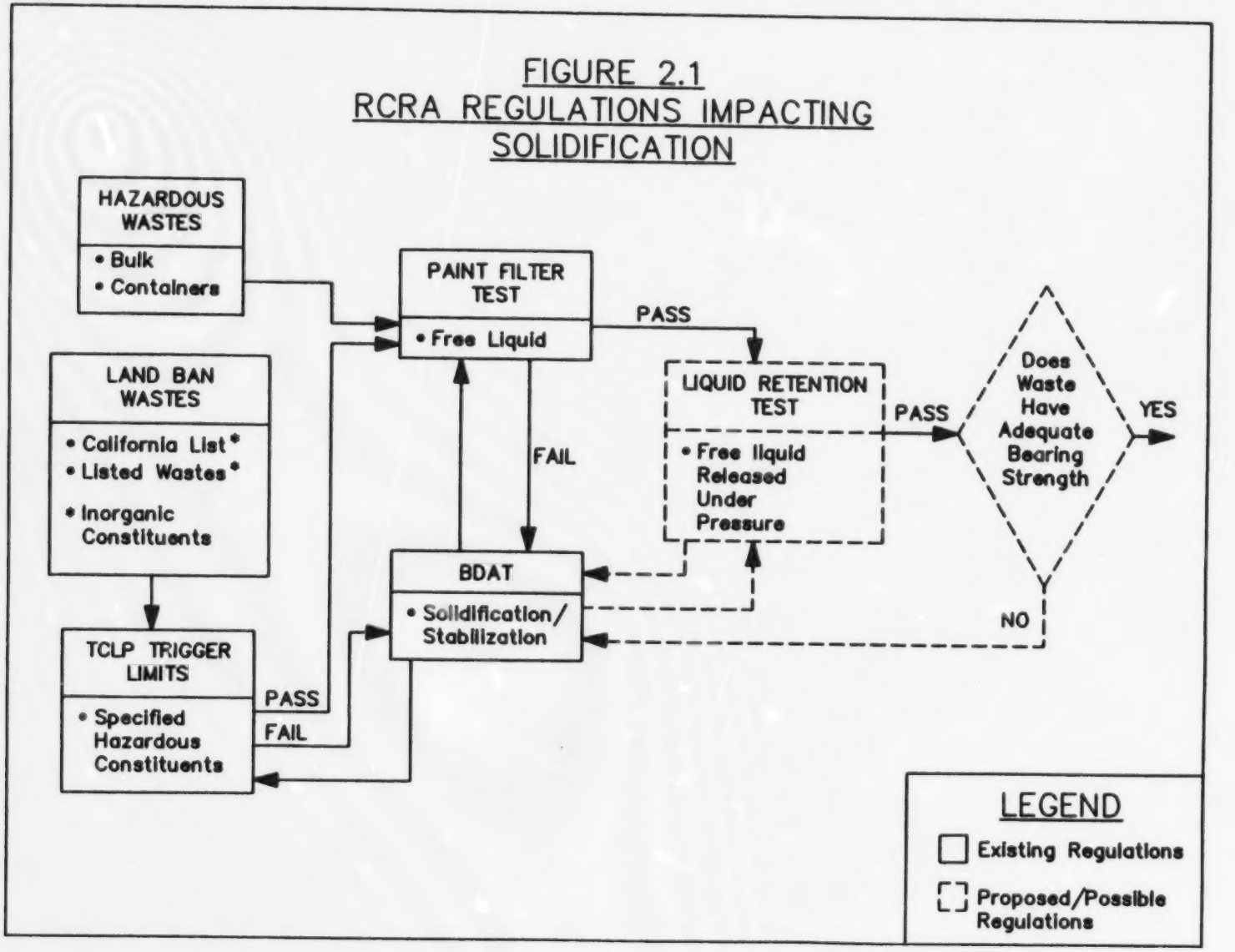
FIGURE 2.1
RCRA REGULATIONS IMPACTING
SOLIDIFICATION
HAZARDOUS WASTES
• Bulk
• Containers
LAND BAN WASTES
• California List*
• Listed Wastes*
• Inorganic Constituents
TCLP TRIGGER LIMITS
• Specified Hazardous Constituents
PAINT FILTER TEST
• Free Liquid
PASS
FAIL
PASS
FAIL
LIQUID RETENTION TEST
• Free liquid Released Under Pressure
PASS
Does Waste Have Adequate Bearing Strength
YES
NO
BDAT
• Solidification/ Stabilization
LEGEND
Existing Regulations
Proposed/Possible Regulations

REFERENCES

R2.1 Environmental Protection Agency, "Lining of Waste Impoundments and Disposal Facilities", Office of Water and Waste Management; SW-870; September 1980.

R2.2 Haxo, H.E. 1980a. Interaction of Selected Liner Materials with Various Hazardous Wastes. In: Disposal of Hazardous Wastes, Proceedings of the Sixth Annual Research Symposium. EPA-600/9-80-010. U.S. Environmental Protection Agency, Cincinnati, Ohio. pp. 160-180. PB 80-175086.

R2.3 White, R.M., and H.E. Haxo. 1976. Evaluation of Liner Materials Exposed to Leachate, Second Interim Report. EPA-600/2-76-255. U.S. Environmental Protection Agency, Cincinnati, Ohio. 53 pp. PB 259-913/AS.

R2.4 Environmental Protection Agency, OSWA Policy Directive 9487.00-2A, "Prohibition on Disposal of Bulk Liquid Hazardous Waste in Landfills - Statutory Interpretive Guide", Office of Solid Waste and Emergency Response, EPA 530 SW-86-016, 1986.

R2.5 Environmental Protection Agency, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", EPA Publication SW-846, Superintendent of Documents, U.S. Government Printing Office, second ed., 1982, update I, April 1984, update II, April 1985, Method 9050.

R2.6 Environmental Protection Agency, Federal Register, V. 51(9), January 14, 1986, pp. 1750-1758 (TCLP Procedure).

R2.7 Environmental Protection Agency, "Proposal Under RCRA to Prohibit Land Disposal of Most Free Liquid Hazardous Waste Held in Containers", Federal Register, V. 51, December 24, 1986, pp. 46824-46836.

R2.8 Private Communication with Christopher Ryan: EPA, Washington, D.C.; RCRA State Coordinator; July 29, 1988

SECTION 3
DEVELOPMENTAL HISTORY OF SOLIDIFICATION

SECTION 3
DEVELOPMENTAL HISTORY OF SOLIDIFICATION

GENERAL BACKGROUND

Solidification refers to a broad class of treatment processes that involve the addition of reagents to the waste to chemically transform the liquid portion of the waste into a solid and to maintain the hazardous constituents in their least soluble and/or least toxic forms (R3.1). The mechanisms by which this occurs depend on the type of solidification process. By adjusting the type and amount of the solidifying agents and other additives, solidification can be applied to a wide range of wastes, from treatment sludge to contaminated soils. Two of the most common solidification processes are: (a)lime/ pozzolan-based processes, and (b)cement-based processes.

The cement-based processes have been selected for the proposed OWMC'S facility. These processes are especially effective for wastes with high levels of toxic metals, because at the pH level of the cement mixture, most multivalent cations are precipitated as hydroxide or carbonate minerals of very low solubility (R3.2). The Portland cement- based process is also effective in removing liquid because the reaction of the anhydrous cement powder and water (liquids) incorporates the water into the solid mineral species. The reaction form produces a colloidal calcium-silicate-hydrate gel of indefinite composition and structure. Hardening of the cement is brought about by the interlacing of thin, densely-packed, silicate fibrils growing from the individual cement particles. The consistency of the solidified waste products will vary depending on waste type, moisture content, organic content, and the type and amount of solidification additives used.

ADVANTAGES OF SOLIDIFICATION

This section discusses the advantages of using solidification in connection with long term disposal of waste residues. The requirement for solidification of the OWMC's waste residues will be discussed in Section 4.

The advantages of solidification can be divided into the following categories:

- o reduction in potential of leak and liquid release;
- o reduction in leachability of contaminants;

- o improvement of physical strength of waste residues to provide handling benefits during winter and prolonged wet periods and to support the overlying wastes and the cover system;

Reduction in Liquid Release Potential

The issue of free liquids has been discussed in detail in Section 2. The Paint Filter Test is now being required by EPA to prevent the placement of free liquids in a secure landfill. As early as 1983, EPA reported that nine out of 30 hazardous waste landfills use or have used solidification for handling free liquids in bulk and container shipments (R3.3).

Improvement of Leaching Resistance

The objective of a long term waste containment system is to isolate the hazardous constituents from the environment for a long period of time. For the landfill disposal method, a small amount of water from precipitation can still infiltrate through the cover into the wastes. In order to limit the potential of migration of the hazardous constituents and protect the groundwater, the mobility of the hazardous constituents will have to be limited. The solidification processes help limit the mobility of a variety of hazardous constituents by introducing both physical and chemical changes in the wastes, as discussed further below.

The cement-based solidification processes reduce the mobility of the hazardous constituents by entrapping them in a cemented matrix with a low permeability, and by converting them into less soluble compounds (R3.4). At the pH level of the cement mixture, most multivalent cations are precipitated as hydroxide or carbonate minerals of very low solubility (R3.2).

In order to quantify the mobility of hazardous constituents from wastes after landfilling, the EPA established a laboratory batch leaching test, known as the Extraction Procedure (EP). This procedure employs a dilute solution of acetic acid as the leaching medium. This volatile fatty acid is common in leachate from sanitary landfills, since it is a byproduct of the first stage of anaerobic degradation. The EP can be considered an aggressive procedure for solidified waste residues in an engineered landfill as it simulates the environment to which the waste residues would be exposed if they were placed in a sanitary landfill and saturated with the landfill leachate (R3.1). (The equivalent test procedure in Ontario is the Leachate Extraction Procedure, as developed by the Ministry of the Environment.)

In responding to criticisms of this test procedure, the EPA has developed a new test (R3.5). The Toxicity Characteristic Leaching Procedure (TCLP) differs from the EP in

that the extractant is either buffered acetic acid or dilute acetic acid, depending on the initial pH of the slurried solid.

In August, 1987, the EPA presented technical data regarding the use of solidification to treat California list wastes, involving heavy metals and cyanide (R3.6). The data shows that solidification significantly reduces the metal concentrations in the leachate of the treated wastes, as compared to the concentration from the untreated wastes. In the majority of cases, the metal concentration in the leachate from the treated wastes meet the new proposed prohibition levels.

Data compiled by Mr. J.R. Conner for OWMC show that solidification is effective in reducing the leachability of a variety of hazardous constituents, including heavy metals and organics, such as phenol and PCB (R3.7).

At the OWMC facility, the physical/chemical treatment processes would have altered the chemical form of the hazardous constituents either by outright destruction (such as in the case of cyanide) or by converting them into less soluble forms (such as metal hydroxides and metal sulphides). The issue of relative dissolution of metal hydroxide/ sulfide sludges is yet unclear. One recent study indicated that hydroxide sludges behaved as expected with the greatest degree of solubilization exhibited at pH 5. The metal sulfide system was more complex; the dissolution behavior was governed by pH, ion exchange, adsorption, and precipitation (R3.8). Other work has indicated that metal sulfide sludge was three times less subject to leaching at pH 5 compared to hydroxide sludge (R3.9). Solidification in this case will ensure that these compounds are kept immobilized in a low-permeability matrix, thus further reducing the risks that they will redissolve in water and migrate.

Immobilization of metals is of primary significance for the residual ashes from incineration. Clapp et al (R3.10) presents the results of a laboratory investigation to determine the chemical characteristics of residual fly and bottom ashes from incineration of infectious hospital wastes and municipal solid wastes. They concluded that the amount of heavy metals available for leaching in the fly ash was quite high. They also concluded that the type and amount of heavy metals in the effluent fly ash appear to be more dependent on the operating parameters of the incinerator than on the influent waste type.

Improvement of Physical Characteristics

Solidification of waste residues will generally result in increases in the strength, stiffness, and bearing capacity of the treated materials. In many instances, the improvement in strength, stiffness, and bearing capacity will be required to facilitate handling and transportation of the materials. In other instances, this improvement might be required for a more fundamental reason of supporting the landfill cap. CECOS routinely solidifies sludges received at its Livingston, Louisiana, hazardous waste landfill.

This is because the wastes originate from the petroleum industry - have high oil contents and are difficult to handle (R3.11).

The solidified waste products from cement-based processes vary in consistency from a weak soil-like or clay-like material to a hard, concrete-like mass. The consistency depends on a variety of factors including waste type, moisture content, organic content, and the type and amount of solidification/stabilization additives used.

The actual consistency and strength of the mass will depend on the amount of cement and additives, as well as the type of wastes. Generally, a higher strength can be correlated with smaller long term deformations, as well as a smaller liquid release potential (R3.2). A higher strength and a more rigid mass can be achieved by increasing the cement and/or additive ratios in the formulations. For strength testing, the EPA has proposed to use the test procedure modeled on ASTM D2166-85, Unconfined Compressive Strength of Cohesive Soil.

DISADVANTAGES OF SOLIDIFICATION

This section discusses the disadvantages of using solidification in connection with long term disposal of waste residues. The disadvantages of solidification can be divided into the following categories (R3.12):

- o increased operating costs,
- o increased fugitive dust emissions and increased worker exposure to the hazardous waste during treatment,
- o changes in the waste volume after treatment.

Increased Operating Costs

Solidification will increase overall disposal costs by about 20 to 35% (R3.7). The implication is that incremental cost is offset by the health and environmental benefits. In the U.S., EPA no longer performs a cost-benefit analysis but rather estimates the total cost of implementing a regulation. Cost-benefit analyses have been shown to be overly subjective and are no longer used by EPA.

Increased Fugitive Emissions

The handling of Portland Cement will tend to increase fugitive emissions at the facility site. In addition, the treatment of the waste in the solidification plant will also tend to increase worker exposure. Emissions from both sources can be mitigated by covering all mixing and conveying equipment.

Changes in Waste Volume

When a solidification agent is added to a waste, the volume will typically increase. For some wastes with high solids contents and few interfering compounds, the volumeric increases will be minimal. For other wastes with low solids contents and interfering compounds, the volume increases can be greater than 50% (R3.13).

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R3.1 U.S. Army Environmental Laboratory, "Guide to the Disposal of Chemically Stabilized and Solidified Waste", Report SW-872, Municipal Environmental Research-Laboratory Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1982.

R3.2 Environmental Protection Agency, OSWA Policy Directive 9487.00-2A, "Prohibition on Disposal of Bulk Liquid Hazardous Waste In Landfills - Statutory Interpretive Guide", Office of Solid Waste and Emergency Response, EPA 530 SW-86-016, 1986.

R3.3 Gilbert, P.A. and Murphy, W.L., "Prediction/Mitigation of Subsidence Damage to Hazardous Waste Landfill Covers", Report EPA/600/2-87/025, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency; Cincinnati, Ohio; September 1986.

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R3.9 Whang, J.D., D. Young, and M. Pressman, "Soluble Sulfide Precipitation for Heavy Metals Removal from Wastewaters," Environmental Progress, 1(2), 110, (1982).

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R3.11 Private Communication with Peter Tarnowski; CECOS- Niagara Falls; August 1, 1988

R3.12 Pojasek, R.B., Toxic and Hazardous Waste Disposal, Volume One, Ann Arbor, Michigan; Ann Arbor Science, 1979.

R3.13 Wiles, C.C., "A Review of Solidification/Stabilization Technology." Journal of Hazardous Materials, Elsevier Science Publishers B.V., Amsterdam; Vol. 14, 1987; pp 5-21.

SECTION 4
APPLICABILITY OF SOLIDIFICATION TO OWMC

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APPLICABILITY OF SOLIDIFICATION TO OWMC

This section will focus on the U.S. regulatory experience and combine it with the technical applicability of solidification to the OWMC facility.

OWMC WASTE RESIDUES

Table 4.1 presents the types, amount, and chemical and physical characteristics of the waste residues, which are candidates for solidification at the OWMC's facility (R4.1). The following are summary comments:

- Selected residues from the waste generators' facilities. Their consistency could range from that of a dry solid to that of a paste or sludge.

- Residues from the physical/chemical treatment plant, comprising batches of filter cakes, with the consistency ranging from friable to pasty. These filter cakes will typically contain inert materials, such as sand or clay particles which were present in the untreated wastes, along with the solids precipitated during the physical/chemical treatment processes. These precipitates will include varying concentrations of slightly soluble salts (e.g., calcium sulfate and calcium carbonate) and precipitated metal hydroxides and sulfides. Some batches of filter cake are likely to contain immiscible or dissolved organics which have been adsorbed on to the solid particles or remain in the cake moisture. (The maximum allowable concentration of trace organics permitted in residues for solidification will be established by leaching tests. Residues containing higher concentrations of trace organics will be incinerated.)

- Residues from the incineration plant comprising ash from the kiln and boiler and salts and ash from the flue gas treatment system. These residues will be substantially dry.

- o Blowdown from the evaporator, which is used to dispose of treated effluent from the physical/chemical plant. Typically, this stream will contain up to 35% dissolved solids.

- o Flushing water.

PHYSICAL CHARACTERISTICS OF WASTE RESIDUES

The physical characteristics of the waste residues, particularly that related to the liquid release potential, have a strong influence on the effectiveness of solidification. From Table 4.1, the following observations can be made:

(1) Incineration salt and ash are essentially dry.
(2) Evaporator blowdown and flushing water are essentially liquid.
(3) The low solid residues are in the form of sludge.
(4) The high solid residues, which are primarily filter cake, have the appearance of solids.

At present, the ranges of the physical properties, i.e., strength and compressibility, of the high solid residues are not available. Ontario Regulations currently prohibit land disposal of hazardous wastes which do not pass the Slump Test. The Slump Test is less conservative than the U.S. Paint Filter Test and will tend to allow a greater percentage of free liquid. Based on ES's previous experience, the OWMC filter cake (depending on oil content, dosage of conditioning agent, precoat additive, clay content, etc.) is expected depending on the waste being treated to contain liquids which will be released under pressure within the engineered landfill.

OPTIONS FOR ULTIMATE DISPOSAL OF WASTE RESIDUES

The residues from the physical/chemical treatment processes and from incineration will ultimately have to be disposed of or stored in such a manner that they will be isolated from the environment for a long period of time. The method for ultimate disposal has a strong influence on the requirement for solidification as a final treatment step of the special wastes. The following section discusses three possible methods for ultimate waste disposal, namely: engineered landfills, above-ground warehouses, and geological isolation.

Engineered Landfills

Landfilling can generically be described as a process for the disposal of wastes in the surficial soils, by burial beneath a layer of soil which acts a cover. The engineered landfill comprises the following components:

- o simple cover,
- o native clay base, and
- o underdrain leachate collection system.

The cover will retard and minimize the rate of infiltration of precipitation into the wastes contained in the landfill, and hence, minimize the formation of leachate. The clay base will retard the migration of leachate and contaminants from the landfill through the native silt and clay to the bedrock aquifer. OWMC's underdrains will be installed as a contingency measure. They provide a means for collecting the leachate generated in the landfill for testing and treatment, if necessary.

Above-Ground Warehouses

An above-ground warehouse for long term containment of hazardous waste residues will protect the wastes from precipitation, surface and ground water, and, at the same time, protect the ground water from the wastes and any leachate which might be produced. Because the structure is above ground, it can be located at sites with a variety of hydrogeological conditions.

The above ground warehouse would be constructed of metal clad roofs and walls, with a concrete floor slab (R4.2). The floor slab would be at a higher elevation than the surrounding grade to restrict the entry of surface water into the warehouse. The solidified residues would be placed in the warehouse and contained there in perpetual storage. The warehouse would be maintained in an essentially leak-proof condition over an indefinite period of time. Diversion ditches and collection ponds for rain water retention would also be provided.

Geologic Isolation

Geologic isolation of residues in mines can take place in an existing mine partially or totally converted for this use, or, alternatively, in a new mine developed solely for this use. The important factors for consideration of any specific mine setting for disposal are geologic and hydrogeologic settings, and underground capacity. Evaluation of the mine disposal options for OWMC concluded that the most suitable and cost effective mine disposal option is the use of one of the existing

salt mines of the Salina Formation. In this option, the waste residues will be placed in the salt caverns of the selected mine.

Salt, which is known in its mineral form as halite, possesses several characteristics which make it suitable as a medium for perpetual waste containment:

(1) Salt is so low in permeability that, for all practical purposes, it can be considered as impermeable. This quality allows a salt mine to contain the waste, as well as to prevent external water from entering and migrating through the waste.
(2) Salt is strong enough to support the roof of the cavern and also to withstand the stresses resulting from the mining operation, without undergoing significant fracturing.
(3) Salt tends to creep under the overburden pressure. This visco- plastic material behavior contributes to the low permeability of a salt formation by preventing the occurrence of fractures. This quality would also cause any voids between the cavern walls and the hazardous waste mass in the mine to be minimized or closed.

REQUIREMENT FOR SOLIDIFICATION OF OWMC'S WASTE RESIDUES PRIOR TO ULTIMATE DISPOSAL

Engineered Landfills

The performance of the engineered landfill will depend, to a great extent, on the characteristics of the wastes it contains. In order for the landfill to satisfactorily perform its function, the wastes it contains must meet the following conditions:

(1) They must permit the construction of the cover, i.e., they must have a sufficient bearing capacity to support the use of heavy construction equipment to properly place and compact the clay material for the landfill cover.
(2) The wastes must be able to support the weight of the cover without undergoing excessive deformation over the long term, leading to excessive settlements, differential settlements, or cracking of the cover. Deformation of the wastes can be caused by the physical process of consolidation (i.e., volume change) or to a lesser degree by biodegradation.

(3) Minimum potential liquid release. The presence of liquids in the wastes in a long term containment system can potentially lead to leaching and migration of hazardous constituents in the wastes. Thus, the wastes should not contain any liquids which can separate from the solid portion under the ambient temperature and pressure of the overlying wastes and cover.

(4) Resistance to leaching. Over the long term, a small amount of water from precipitation will infiltrate through the cover into the wastes. If the solubility of the hazardous constituent is limited, then the potential for their migration out of the landfill will be reduced.

ES has extensive project experience on the dewatering of industrial and hazardous waste sludges. Based on our previous experience, ES believes that without solidification, the waste residues shown in Table 4.1, excluding the incineration residues, will typically have an unconfined compressive strength of 69 kPa (10 psi) or less. To provide an adequate foundation for the construction of the landfill cover, the underlying wastes probably need to have the same consistency and strength as that of compacted clay or silt. A range of unconfined compressive strength of 50 to 100 kPa (7 to 15 psi) is typical for these compacted soils (R4.3, R4.4, R4.5). OWMC's solidified material will, however, have an unconfined compressive strength exceeding 1,000 kPa (R4.6). Therefore, solidification improves the compressive strength of the waste and minimizes the likelihood of differential settlement.

Qualitative Landfill Assessment

The requirement for solidification for different types of waste residues at the proposed OWMC facility has been assessed by Engineering- Science and summarized in Table 4.2 for ultimate disposal in an engineered landfill. The description of the waste residues are similar to Table 4.1. All of the waste residues, with the exception of the incinerator ash, will require solidification in order to support the construction of the landfill cap and to ensure that they will not readily release any liquids under the pressures in the landfill. For the incinerator ash, solidification will be required to minimize the leachability of the heavy metals it may contain.

The above assessment is based on the entire range of the physical characteristics shown in Table 4.1. As explained in Section 2, solidification is being

required in the U.S. by recent regulatory changes and as such is used to eliminate free liquid and to reduce leachability.

Above-Ground Warehouses

The performance of an above-ground warehouse will depend on its design and the characteristics of the wastes it contains. In order for the above-ground warehouse to satisfactorily perform its function, the following conditions must be met:

(1) The warehouse structure must be able to completely contain the wastes. Consequently, waste residues in liquid form or containing free liquid must be contained in compartments which are leak-proof and which cannot be easily corroded by contact with the waste residues.
(2) There should be a minimum potential of waste migration in case of leak or structural failure. Consequently, the wastes should not be in a liquid form nor should they contain any liquids which can readily separate from the solid portion under the pressure of the overlying wastes.

Qualitative Warehouse Assessment

A qualitative assessment for solidification for different types of waste residues at the proposed above ground warehouse facility has been assessed and summarized in Table 4.3. The characteristics of the waste residues are described in Table 4.1. For disposal in an above-ground warehouse, all components of the waste residues, with the exception of incinerator ash, will require solidification in order to minimize the potential of contaminant migration in the event of leak or structural failure. As long as the roof structure remains intact, solidification of the incinerator ash would not be required.

Applicability of Warehouses

There are no known facilities currently in operation in the U.S. or Canada which warehouse hazardous wastes for a planned period of hundreds of years. However, the state of Georgia has recently mandated solidification of wastes prior to warehousing for a conceptual design currently being prepared (R4.7).

Geologic Isolation

Waste deposition in the salt mine can be accomplished using four different methods. These methods and their suitability for long term waste containment are discussed in the following paragraphs:

(1) Deposition of liquid waste or waste residue. This method is unsuitable for long term waste containment because there is a potential for waste migration through a leak or open fractures. In addition, water in the waste will dissolve the salt with which it is in contact until the water becomes saturated with salt. Although this is unlikely to be a major problem in a massive salt formation, it nonetheless presents some difficulties in terms of control and monitoring of the disposal mine.

(2) Deposition of waste in containers. In this method, the waste is lowered into the cavern in individual canisters or containers. This method is expected to be time consuming and labor intensive (R4.8). In addition, over the long term, the containers will be subject to corrosion and might leak or fail.

(3) Disposal of solidified waste in slurry form. In this method, a solidifying agent is mixed with the waste in slurry, which is pumped down into the cavern. The solidifying agent is selected so that the mixture will gel and harden after it has been deposited in the cavern. This method is suitable for long term waste containment, and is particularly suited for wastes with a low solids content.

(4) Disposal of solidified waste in pellet form. In this method, the solidified waste is extruded or formed as pellets or chunks, which is delivered into the cavern via a pipe or an elevator. This method is suitable for long term waste containment, and is particularly suited for wastes with a high solids content.

Qualitative Underground Assessment

A qualitative assessment of solidification for different types of waste residues at the proposed underground (salt mine) facility has been assessed by ES and summarized in Table 4.4. The characteristics of the waste residues are as described in Table 4.1. For disposal in a salt mine, all components of the waste residues, with the exception of incinerator ash, will require solidification in order to minimize the potential of contaminant migration through leaks or fractures and to prevent dissolving of the salt by water contained in the waste residues.

Applicability of Geologic Isolation

This disposal method has previously been considered primarily for disposal of radioactive wastes. In the U.S., HSWA (Section 3004(b)) banned the placement of liquid hazardous waste in salt domes, underground mines, or caves. The legislative language has been interpreted to preclude the use of such locations for treatment.

Consequently, placement of bulk liquid waste which has been mixed with the appropriate solidification agents but which has not yet gelled or hardened, would also be prohibited (R4.9).

TABLE 4.1

OWMC TREATMENT RESIDUES REQUIRING SOLIDIFICATION

DESCRIPTION OF WASTES AND RESIDUES	EXPECTED QUANTITY (t/a)	MATRIX CHARACTERISTICS	
		CHEMICAL	PHYSICAL
1. High Solids Residues from Generators	16,100	Metallic sulfides or metallic hydroxides with some calcium hydroxide or sulfide chemicals	20-40% inorganic solids 80-60% water Fine-grained sludge
2. Wet Nonpumpable Residues from Generators	16,700	Wide range of inorganic compounds	5-30% inorganic solids 95-70% water nonpumpable, gelatinous sludge
3. High Solid Residues from Physical/Chemical Treatment Plant (Filter Cake)	19,000	Hydroxide or salt or sulfide sludge	20-40% inorganic solids 80-60% water Fine-grained sludge
4. Dry Solid Residues from Incineration Plant (Salt and Ash)	6,500	Sodium chloride, sodium sulfate, calcium salts, with trace metals and inert ash (which is mostly silica and iron oxide)	Dry, granular, soluble and insoluble solids
5. Liquid Residues from Physical/Chemical Treatment Plant (Evaporator Blowdown)	20,700	Aqueous salt water with metals	Turbid water
6. Flushing Water	900	Aqueous salt water with metals	Turbid water

SOURCE: R4.1

TABLE 4.2

REQUIREMENT FOR SOLIDIFICATION OF RESIDUES FOR DISPOSAL IN LANDFILLS

DESCRIPTION OF RESIDUES	NEEDS FOR SOLIDIFICATION/STABILIZATION			
	TO REDUCE POTENTIAL FOR LEAK AND LIQUID RELEASE	TO REDUCE LEACHABILITY	TO IMPROVE PHYSICAL CHARACTERISTICS TO SUPPORT COVER AND OVERLYING WASTE	TO PREVENT REACTION WITH SURROUNDING MEDIA
1. High Solids Residues from Generators	Required	Not Required	Required	Not Required
2. Wet Nonpumpable Residues from Generators	Required	Not Required	Required	Not Required
3. High Solid Residues from Physical/Chemical Treatment Plant (Filter Cake)	Required	Not Required	Required	Not Required
4. Dry Solid Residues from Incineration Plant (Salt and Ash)	Not Required	Required	Not Required	Not Required
5. Liquid Residues from Physical/Chemical Treatment Plant (Evaporator Blowdown)	Required	Not Required	Required	Not Required
6. Flushing Water	Required	Not Required	Required	Not Required

TABLE 4.3

REQUIREMENT FOR SOLIDIFICATION OF RESIDUES FOR DISPOSAL IN ABOVE-GROUND WAREHOUSES

DESCRIPTION OF RESIDUES	NEEDS FOR SOLIDIFICATION/STABILIZATION			
	TO REDUCE POTENTIAL FOR LEAK AND LIQUID RELEASE	TO REDUCE LEACHABILITY	TO IMPROVE PHYSICAL CHARACTERISTICS TO SUPPORT COVER AND OVERLYING WASTE	TO PREVENT REACTION WITH SURROUNDING MEDIA
1. High Solids Residues from Generators	Required	Not Required	Not Required	Not Required
2. Wet Nonpumpable Residues from Generators	Required	Not Required	Not Required	Not Required
3. High Solid Residues from Physical/Chemical Treatment Plant (Filter Cake)	Required	Not Required	Not Required	Not Required
4. Dry Solid Residues from Incineration Plant (Salt and Ash)	Not Required	Not Required	Not Required	Not Required
5. Liquid Residues from Physical/Chemical Treatment Plant (Evaporator Blowdown)	Required	Not Required	Not Required	Not Required
6. Flushing Water	Required	Not Required	Not Required	Not Required

TABLE 4.4

REQUIREMENT FOR SOLIDIFICATION OF RESIDUES FOR DISPOSAL IN SALT MINES

DESCRIPTION OF RESIDUES	NEEDS FOR SOLIDIFICATION/STABILIZATION			
	TO REDUCE POTENTIAL FOR LEAK AND LIQUID RELEASE	TO REDUCE LEACHABILITY	TO IMPROVE PHYSICAL CHARACTERISTICS TO SUPPORT COVER AND OVERLYING WASTE	TO PREVENT REACTION WITH SURROUNDING MEDIA
1. High Solids Residues from Generators	Required	Not Required	Not Required	Required
2. Wet Nonpumpable Residues from Generators	Required	Not Required	Not Required	Required
3. High Solid Residues from Physical/Chemical Treatment Plant (Filter Cake)	Required	Not Required	Not Required	Required
4. Dry Solid Residues from Incineration Plant (Salt and Ash)	Not Required	Not Required	Not Required	Not Required
5. Liquid Residues from Physical/Chemical Treatment Plant (Evaporator Blowdown)	Required	Not Required	Not Required	Required
6. Flushing Water	Required	Not Required	Not Required	Required

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R4.8 Blair, R., and Crotogino, F., "Ultimate Containment of Residual Hazardous Waste in Salt Formations", Proceedings, International Conference on New Frontiers for Hazardous Waste Management, September 1985; Pittsburgh, PA; EPA/600/9-85/025.

R4.9 Environmental Protection Agency, OSWA Policy Directive 9487.00-2A, "Prohibition on Disposal of Bulk Liquid Hazardous Waste in Landfills - Statutory Interpretive Guide", Office of Solid Waste and Emergency Response, EPA 530 SW-86-016, 1986.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS

1) The waste residues from the OWMC treatment facility include treatment sludges, filter cakes, blowdown liquid, and incinerator ashes. All of these waste residues are similar to those routinely handled in the United States. Therefore, the regulatory and operational experience in the U.S. should be directly transferable to Ontario.
2) The major thrust of EPA's land disposal regulations has been the elimination of free liquids (as measured by the Paint Filter Test and proposed Liquid Retention Test) and reduction of contaminant leachability. The landfill ban regulations have also encouraged the use of solidification for inorganic compounds since EPA's data is based on BDAT being solidification.
3) The advantages of solidification are as follows: (a) reduction in potential of leak and liquid release; (b) reduction in leachability of contaminants; (c) improvement of physical strength of waste residues to support the overlying wastes and the cover system; and (d) provision of operational/handling benefits during winter and prolonged wet periods.
4) The disadvantages of solidification are: (a) increased waste disposal cost, (b) fugitive dust emissions and increased worker exposure to the hazardous waste during treatment, (c) volumetric increases in the waste after treatment.
5) For disposal in an engineered landfill, all components of the waste residues (see Table 4.2), with the exception of incinerator ash, will require solidification in order to be able to support the construction of the landfill cap and to ensure that they will not readily release any liquids as a result of overburden pressures in the landfill. For the incinerator ash, solidification will be required in a number of instances to minimize the leachability of heavy metals.
6) For disposal in an above-ground warehouse, all components of the waste residues, with the exception of incinerator ash, will require solidification in order to minimize the potential of contaminant migration in the event of a leak or structural failure. An above-ground warehouse has never been used to permanently store hazardous waste, although the State of Georgia is now proposing to use the concept in a state-wide facility currently being evaluated.

7) For disposal in a salt mine, all components of the waste residues, with the exception of the incinerator ash, will require solidification in order to minimize the potential of contaminant migration through leaks or fractures and to prevent dissolving of the salt by water contained in the waste residues. Current U.S. regulations prohibit the use of mines, caves, and salt domes for liquid hazardous waste disposal.

RECOMMENDATIONS

After review of the pertinent data, Engineering-Science concurs in the recommendation that OWMC employ solidification as a final treatment step at its proposed facility. This recommendation is justified in the following manner:

1. Ontario Regulations currently prohibit land disposal of hazardous wastes which do not pass the Slump Test.
2. The Slump Test is less conservative than the Paint Filter Test and will allow a greater percentage of free liquid. With more operational experience, it is considered highly likely that the Ontario Ministry of the Environment will adapt testing procedures similar to the Paint Filter Test, Liquid Retention Test, and the Land Ban regulations including the TCLP. This regulatory action would require an incremental amount of OWMC's wastes to be solidified.
3. Remaining wastes not specifically addressed by existing/ possible Ontario regulations should be solidified in order to improve overall subsidence, increase operational flexibility during wet weather, or to optimize compaction during freezing weather.